(12) UK Patent Application (19) GB (11) 2 350 809 (13) A

(43) Date of A Publication 13.12.2000

(21) Application No 9913360.5

(22) Date of Filing 09.06.1999

(71) Applicant(s)
ADAPTIVE AEROSPACE SOLUTIONS LIMITED
(Incorporated in the United Kingdom)
3 Redman Court, Bell Street, PRINCES RISBOROUGH, Bucks, HP27 0AA, United Kingdom

(72) Inventor(s)
Paul Dennison Walton
Graham Ben Dix

(74) Agent and/or Address for Service
Atkinson Burrington
27-29 President Buildings, President Way, SHEFFIELD, S4 7UR, United Kingdom

(51) INT CL[7]
G05B 19/4093 19/4097

(52) UK CL (Edition R)
B3B BCB28 BCB29
G3N NGBC4 N291 N383X

(56) Documents Cited
GB 2240406 A GB 2234089 A

(58) Field of Search
UK CL (Edition Q) B3B , G3N
INT CL[6] G05B
Online:EPODOC

(54) Abstract Title
Performing mechanical operations upon components

(57) Mechanical operations are performed upon components having initial surface shapes or configurations, in order to achieve a desired surface shape or configuration. An engineering model is identified that defines a preferred surface shape or configuration for a component. A description of at least part of the initial configuration of the component is derived and a component model is defined by manipulating the engineering model with reference to the description. Thereafter, in response to said component model, mechanical operations are performed upon the component, thereby modifying the component so as to bring it into line with the original engineering model while at the same time being sympathetic to part of the initial configuration. The procedure may be used for repair of turbine blades taking account of any distortion occuring in previous use.

GB 2 350 809 A

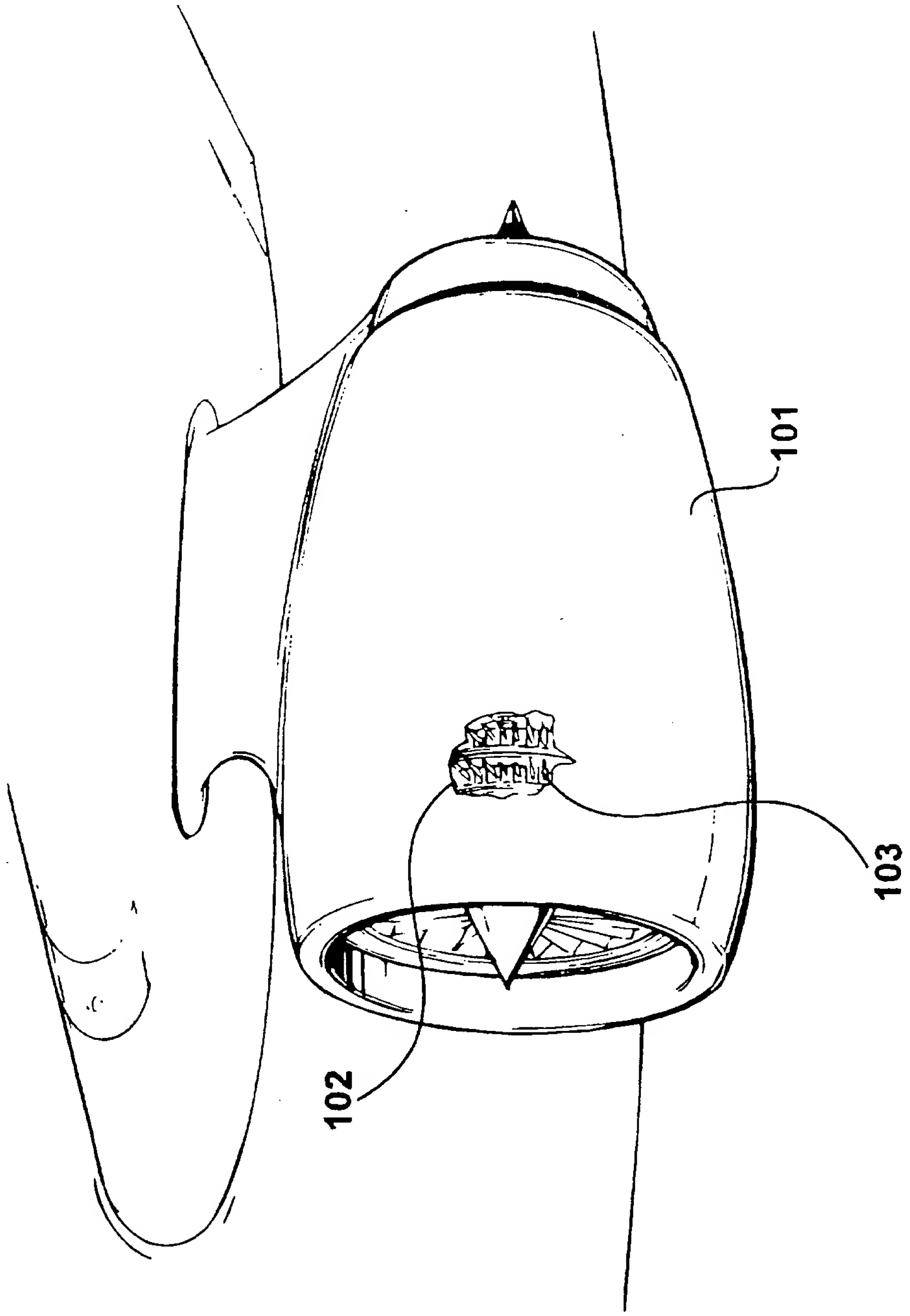


Figure 1

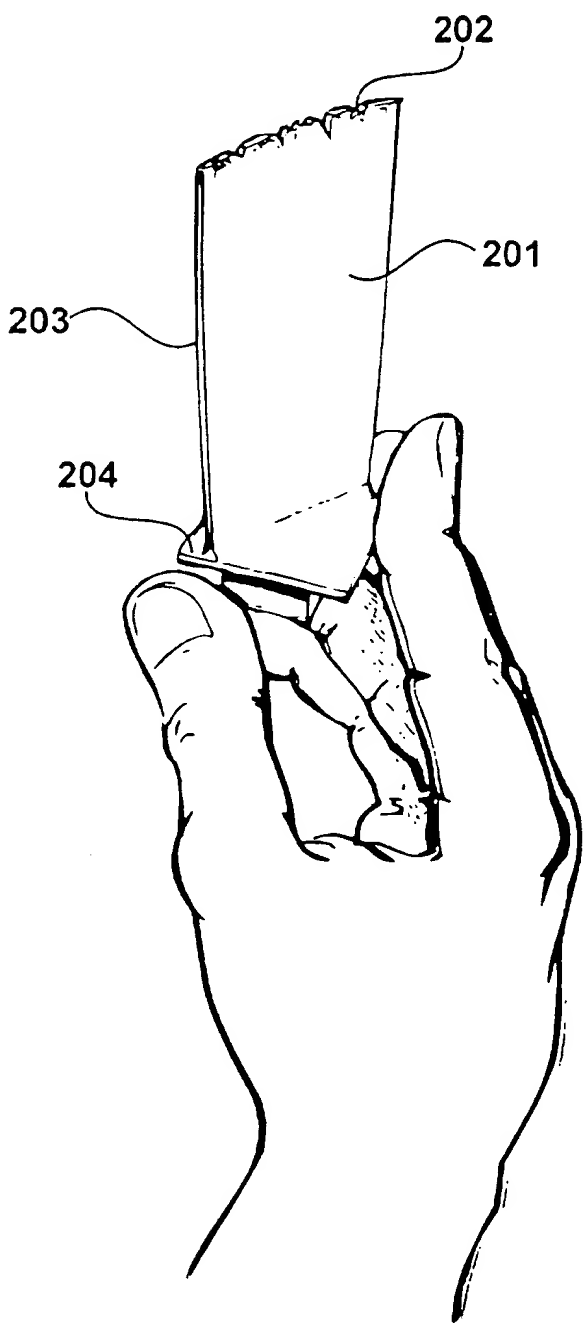


Figure 2

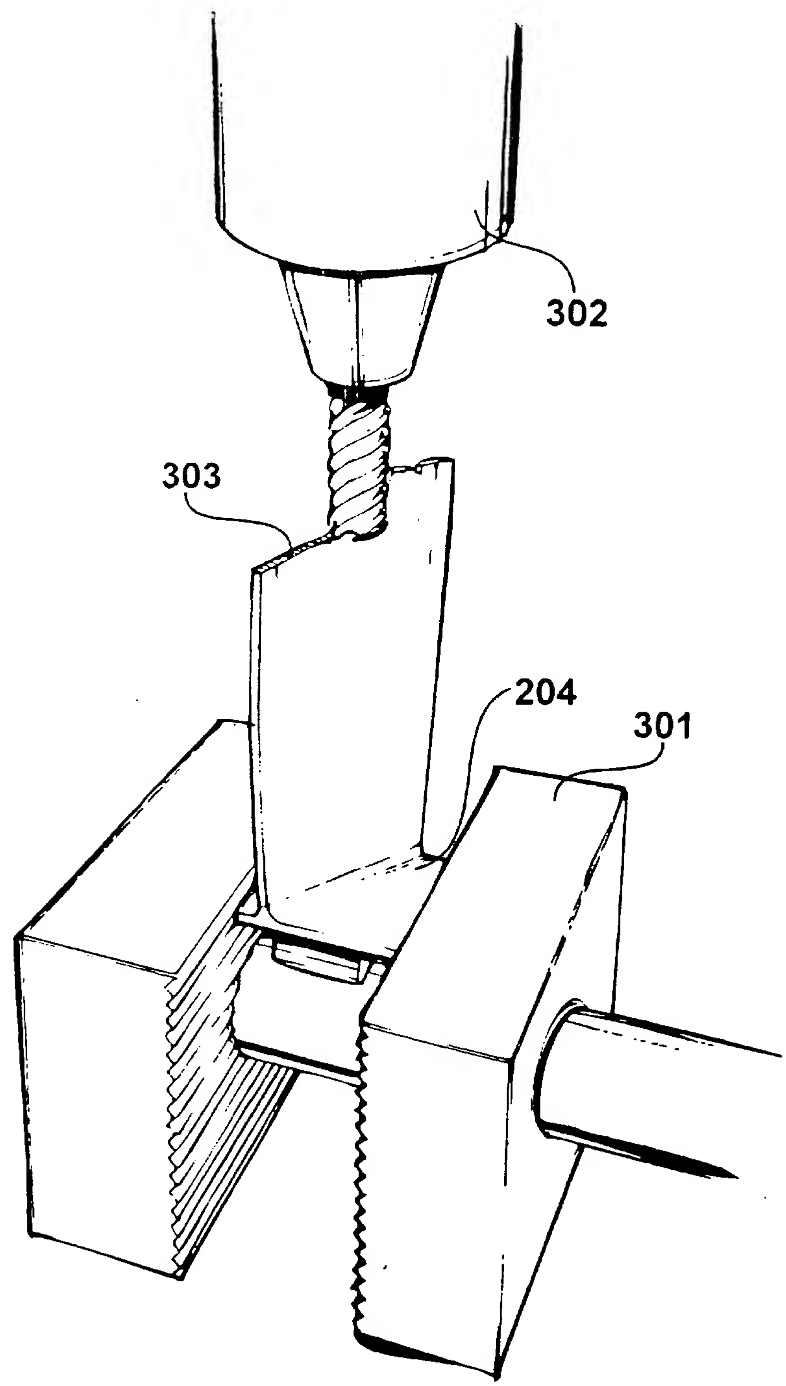


Figure 3

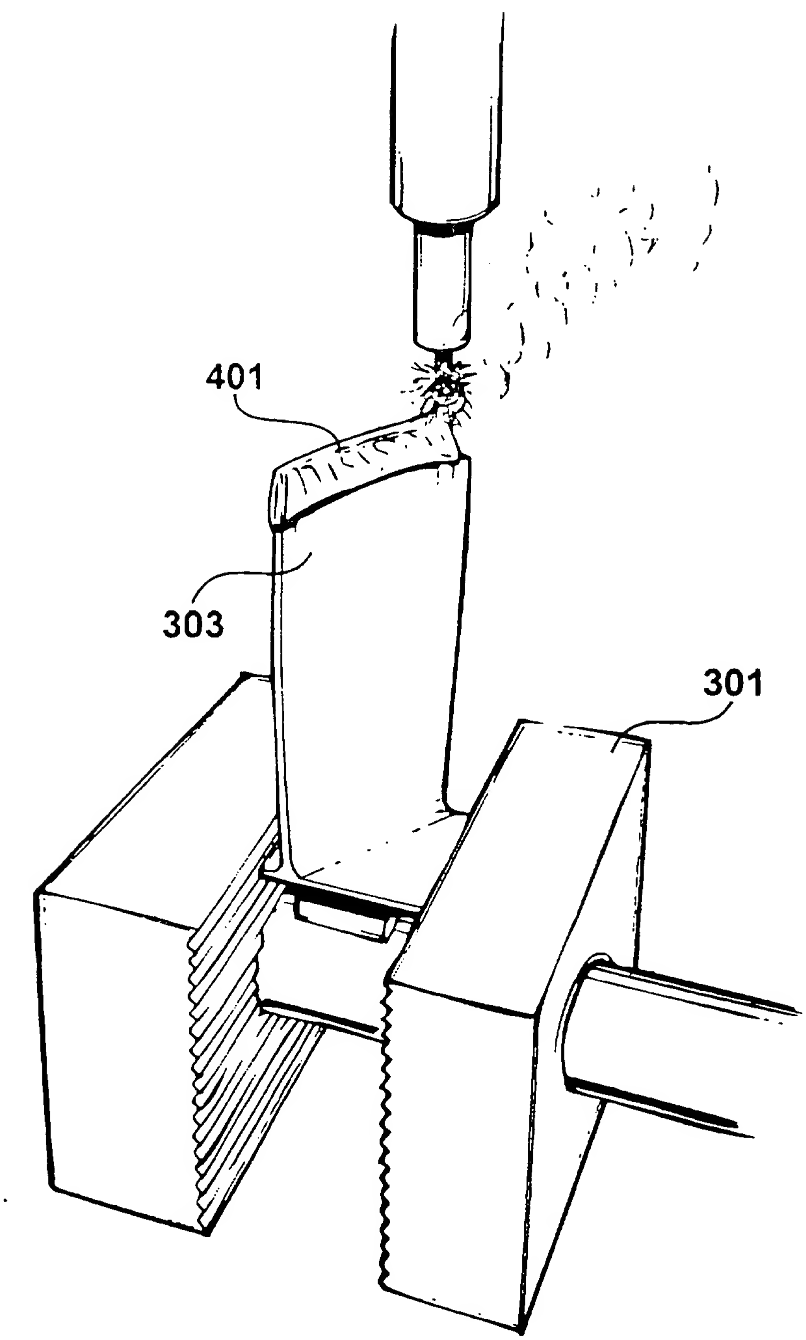


Figure 4

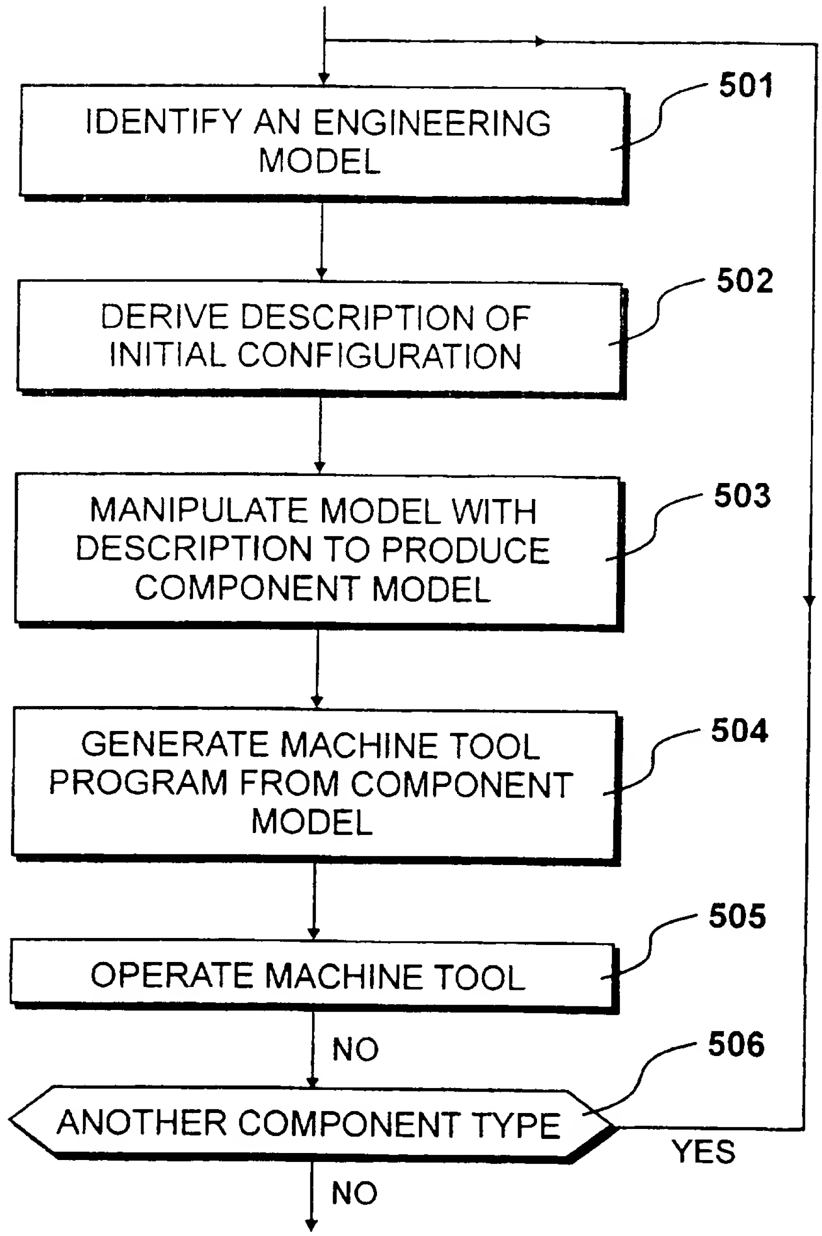

IDENTIFY AN ENGINEERING MODEL
501
DERIVE DESCRIPTION OF INITIAL CONFIGURATION
502
MANIPULATE MODEL WITH DESCRIPTION TO PRODUCE COMPONENT MODEL
503
GENERATE MACHINE TOOL PROGRAM FROM COMPONENT MODEL
504
OPERATE MACHINE TOOL
505
NO
ANOTHER COMPONENT TYPE
506
YES
NO

Figure 5

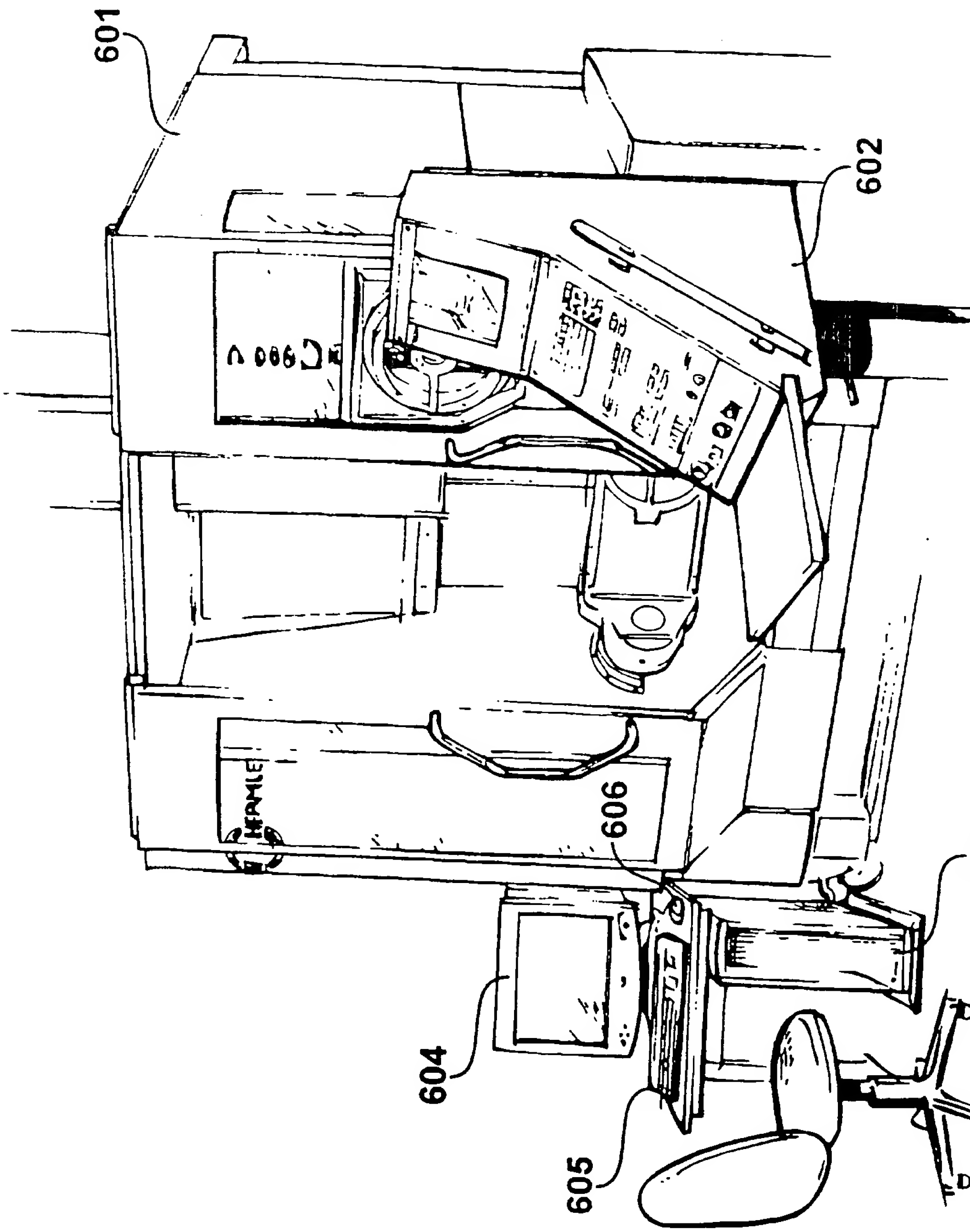


Figure 6

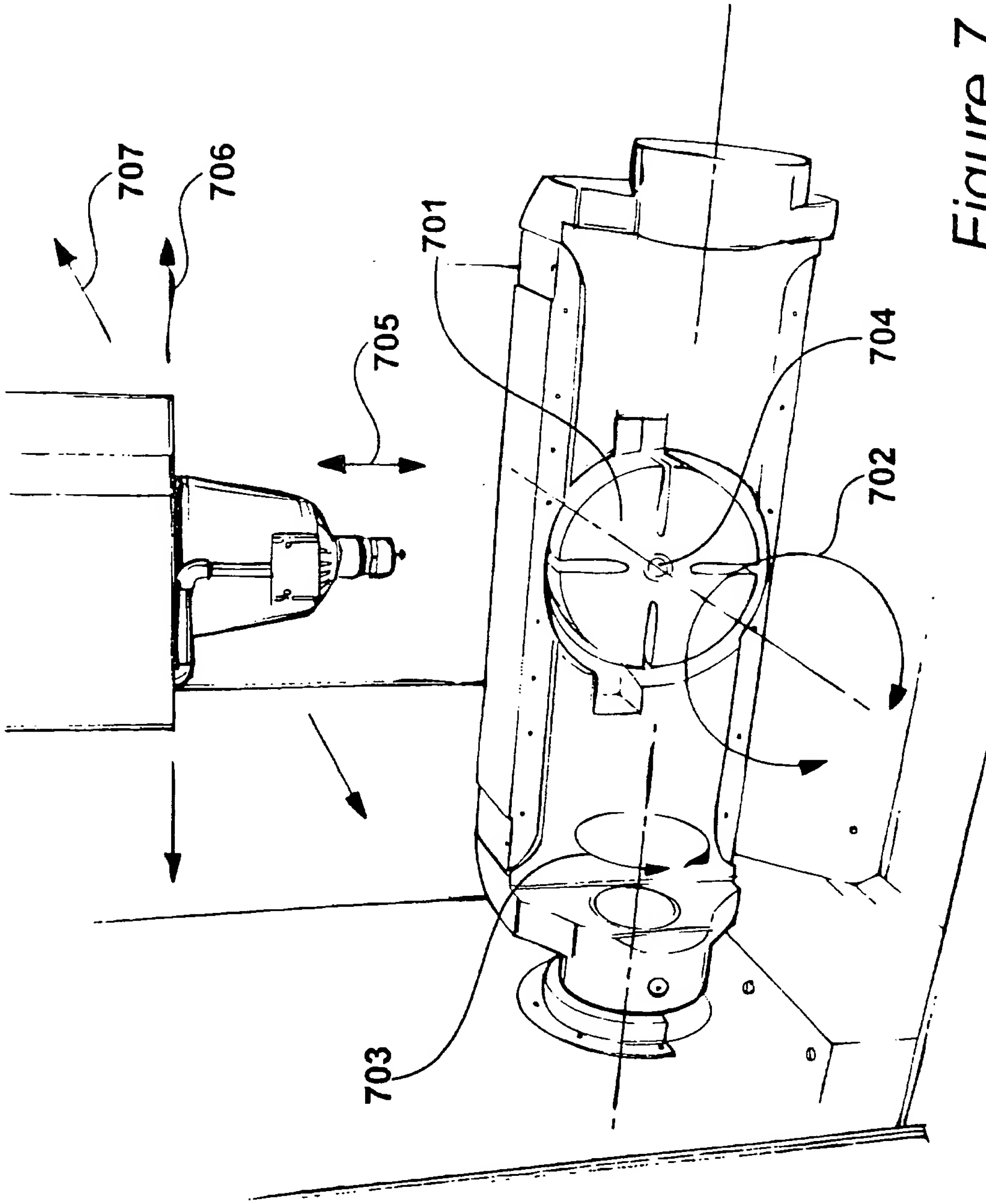


Figure 7

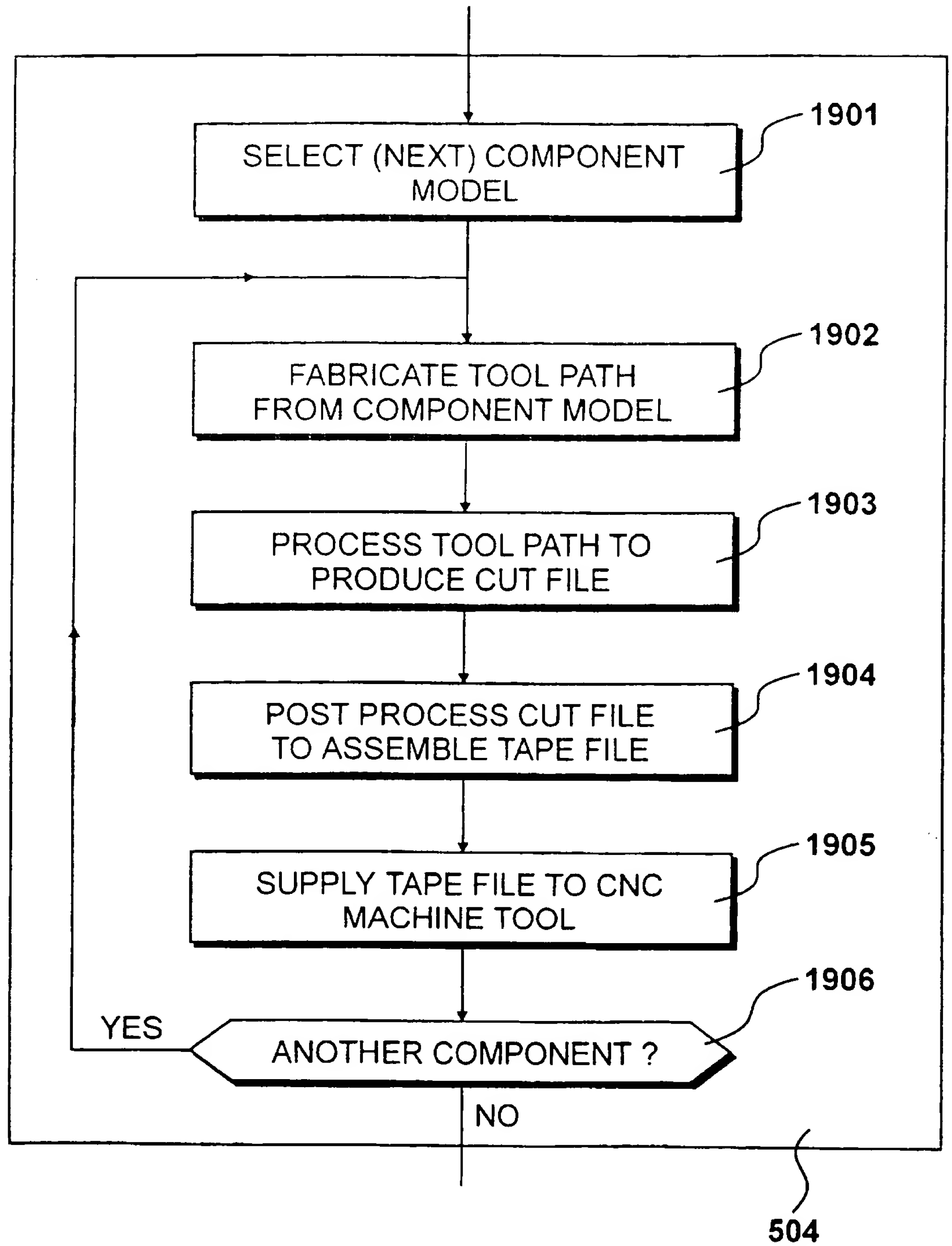
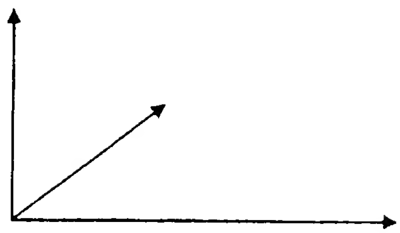

SELECT (NEXT) COMPONENT MODEL
1901
FABRICATE TOOL PATH FROM COMPONENT MODEL
1902
PROCESS TOOL PATH TO PRODUCE CUT FILE
1903
POST PROCESS CUT FILE TO ASSEMBLE TAPE FILE
1904
SUPPLY TAPE FILE TO CNC MACHINE TOOL
1905
ANOTHER COMPONENT ?
1906
YES
NO
504

Figure 19



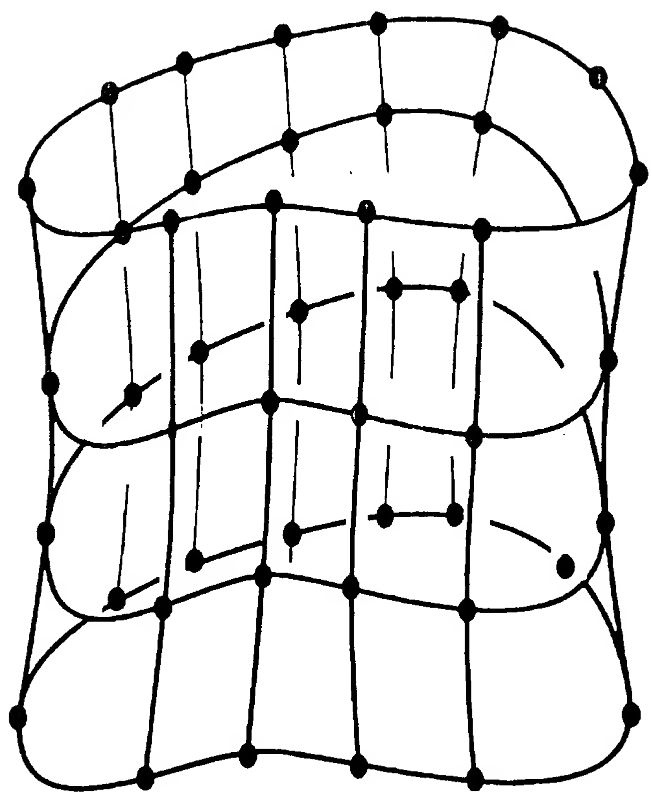


Figure 18

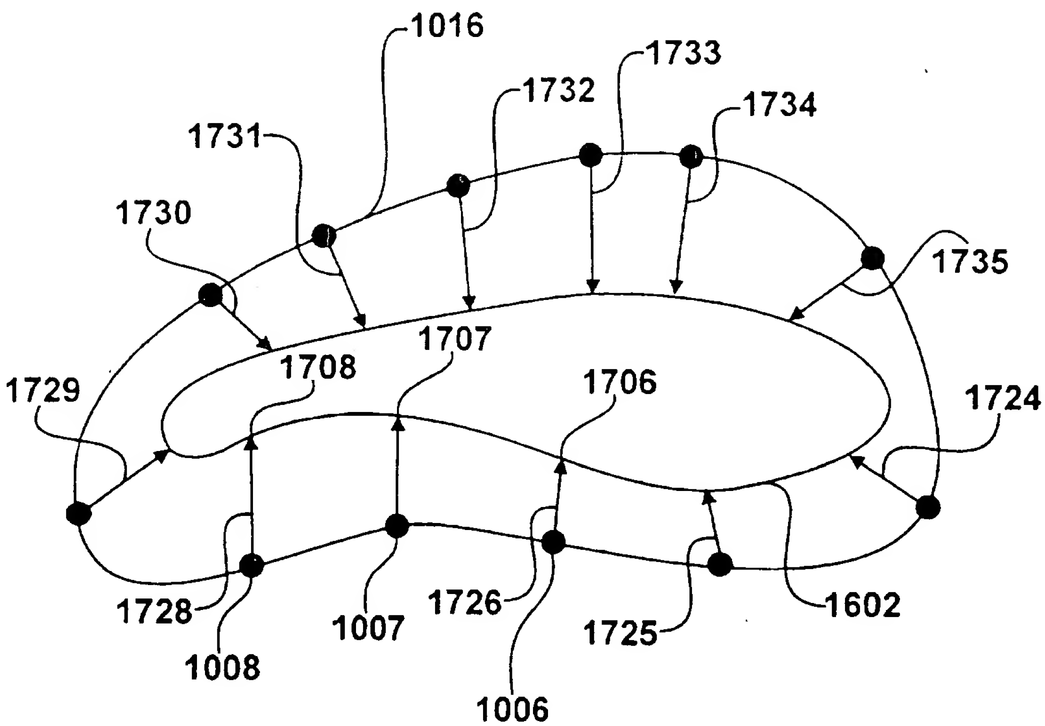

1016
1733
1732
1734
1731
1730
1735
1707
1708
1706
1729
1724
1728
1007
1726
1725
1602
1008
1006

Figure 17

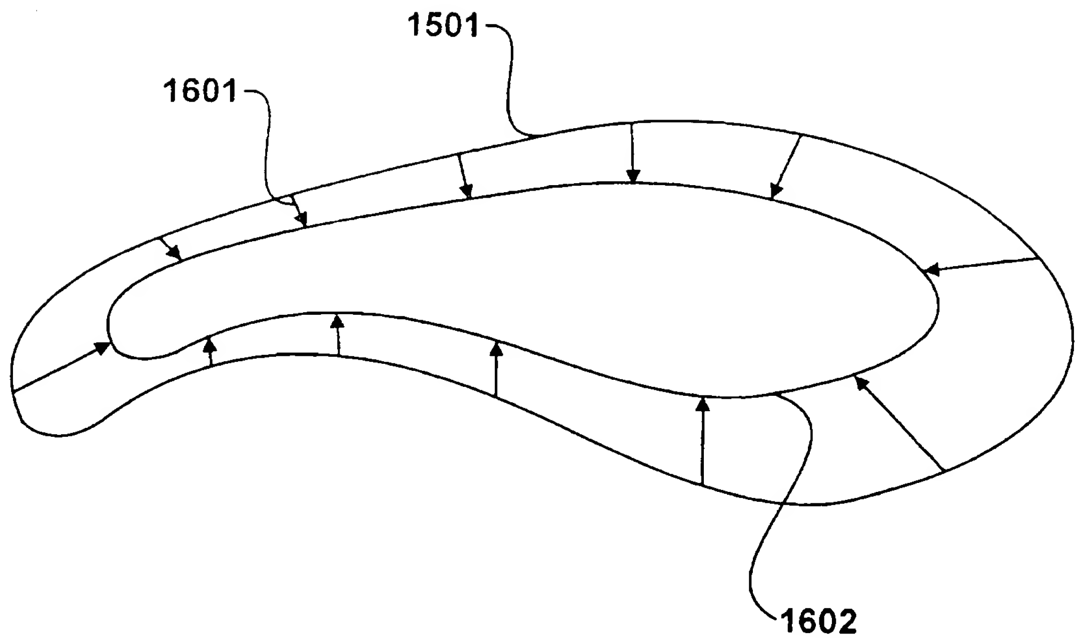


Figure 16

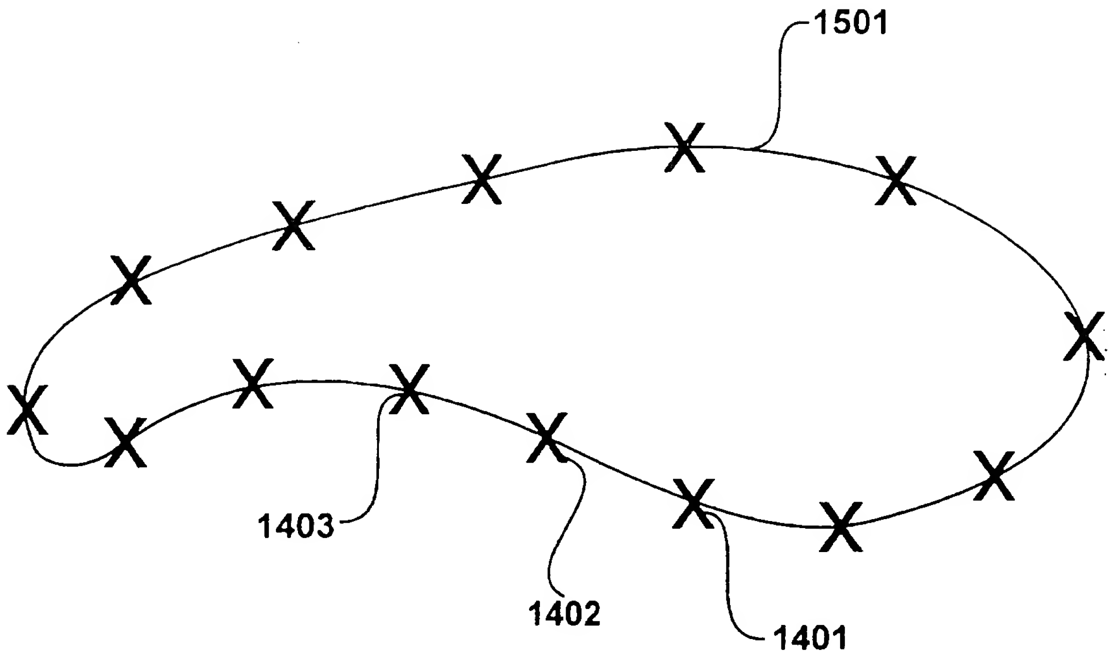


Figure 15

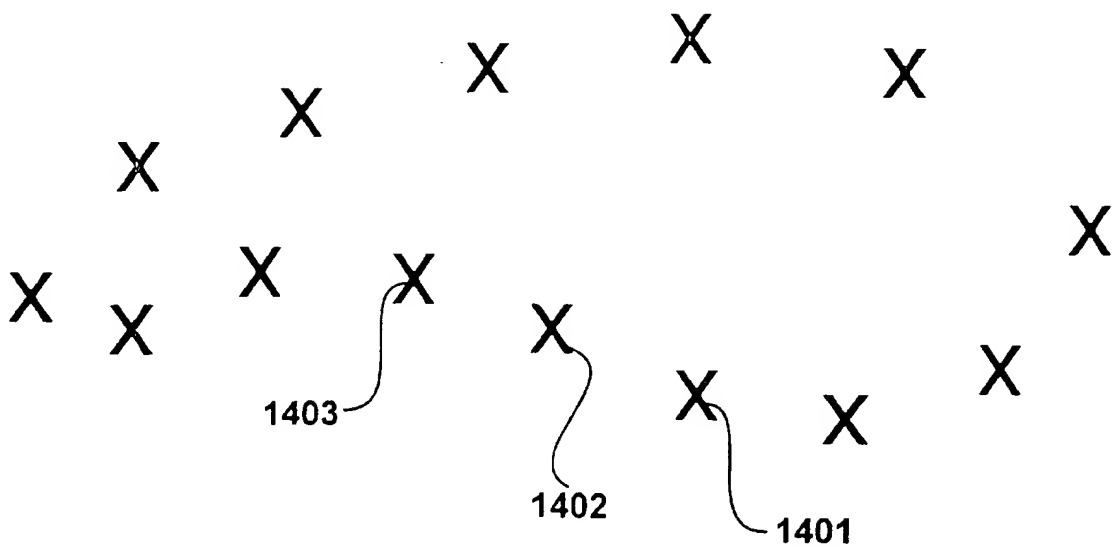


Figure 14

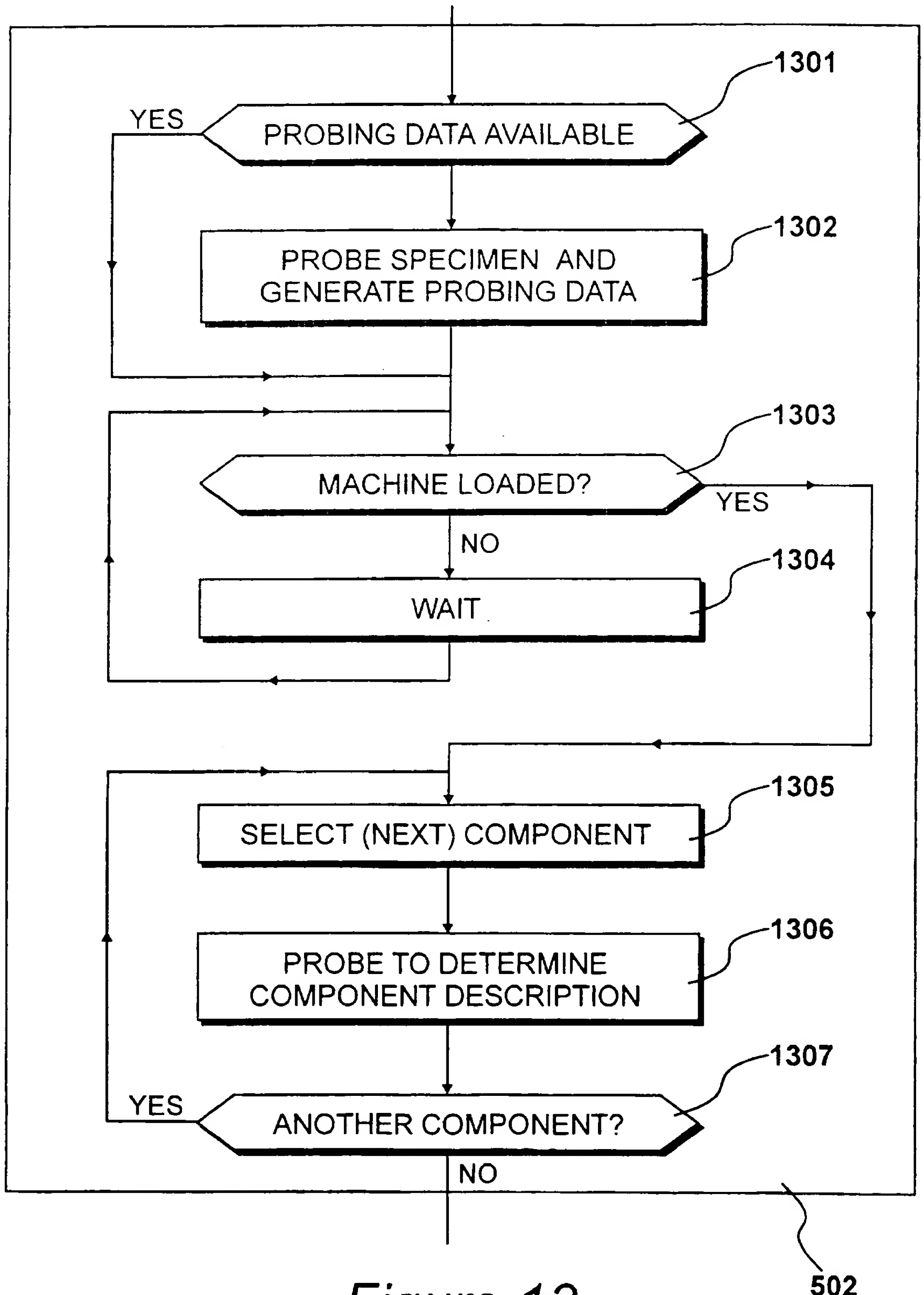

1301
YES
PROBING DATA AVAILABLE
1302
PROBE SPECIMEN AND GENERATE PROBING DATA
1303
MACHINE LOADED?
YES
NO
1304
WAIT
1305
SELECT (NEXT) COMPONENT
1306
PROBE TO DETERMINE COMPONENT DESCRIPTION
1307
YES
ANOTHER COMPONENT?
NO
502

Figure 13

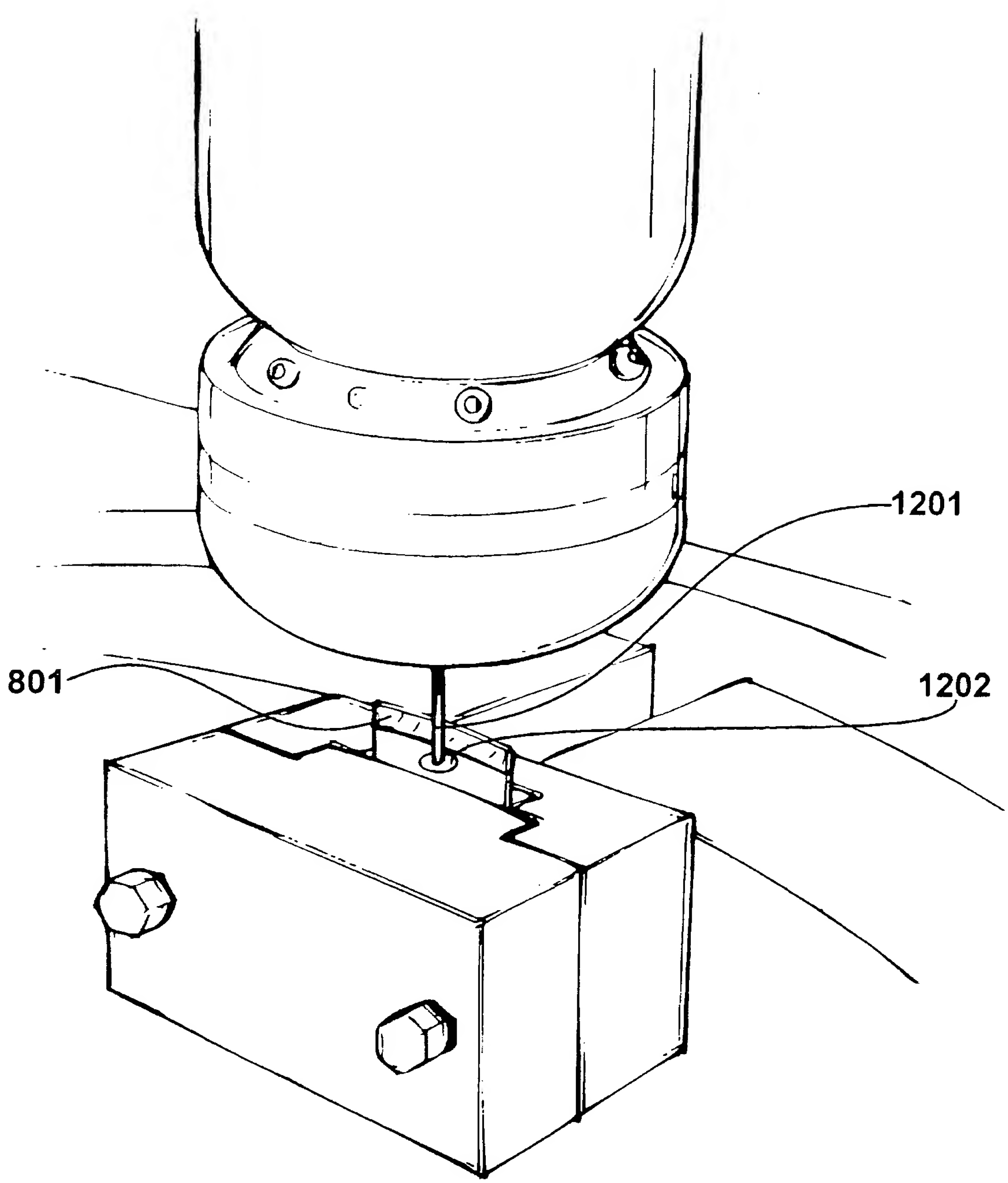


Figure 12

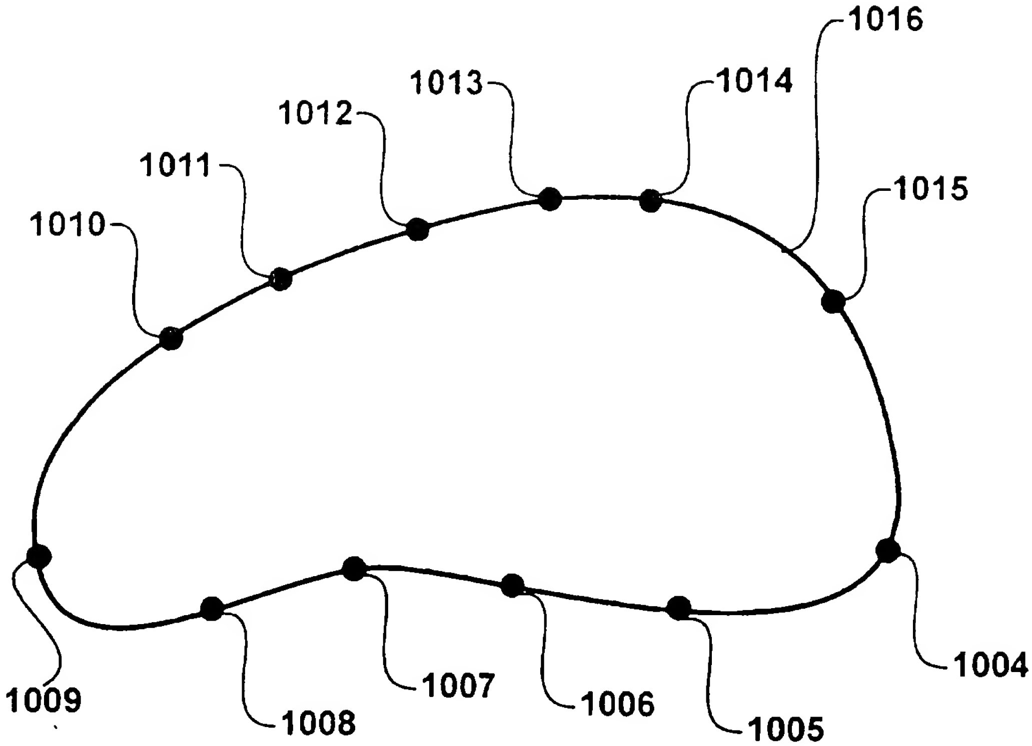

1016
1013
1014
1012
1011
1015
1010
1009
1008
1007
1006
1005
1004

Figure 11

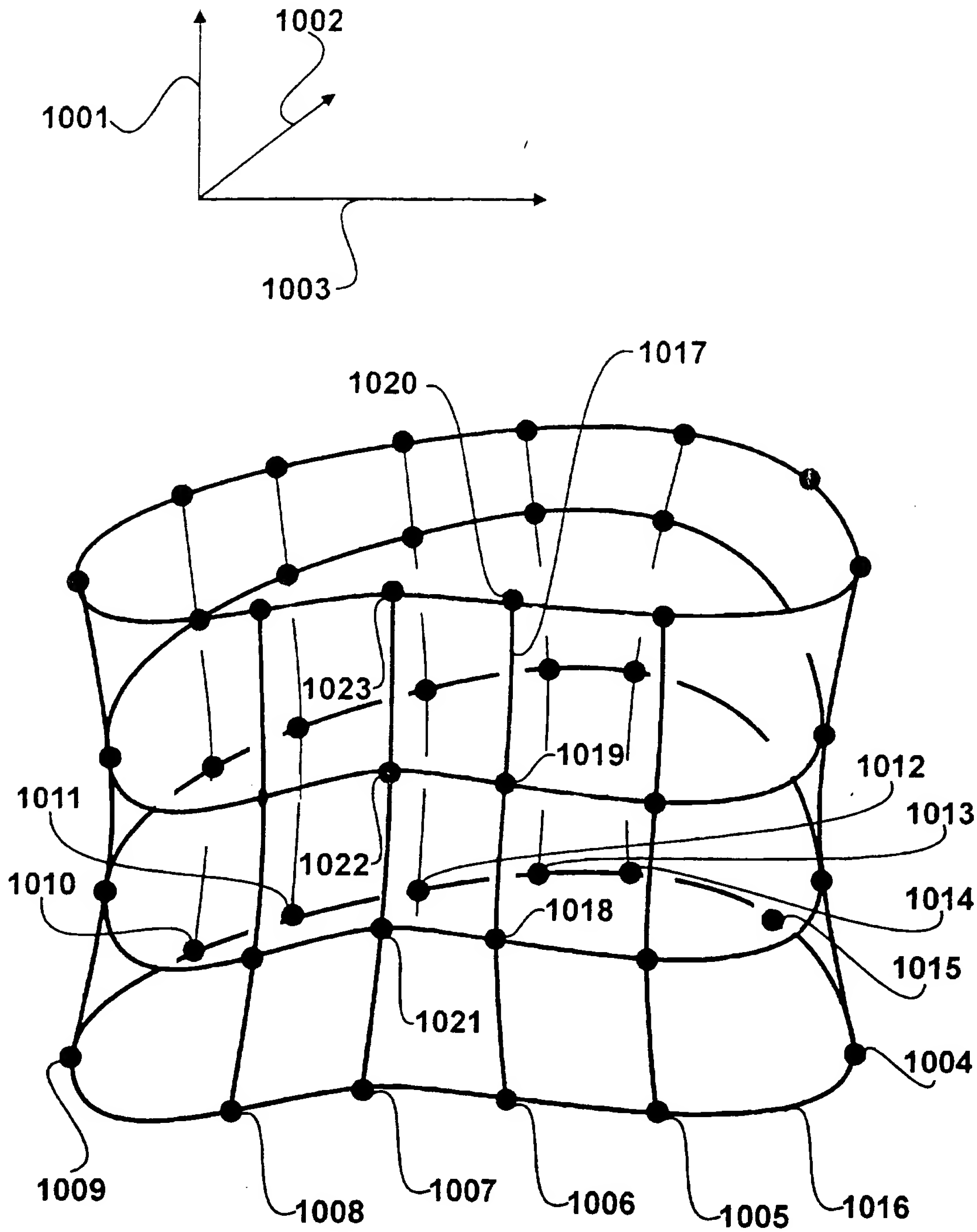

1002
1001
1003
1017
1020
1023
1019
1012
1011
1013
1022
1010
1018
1014
1015
1021
1004
1009
1008
1007
1006
1005
1016

Figure 10

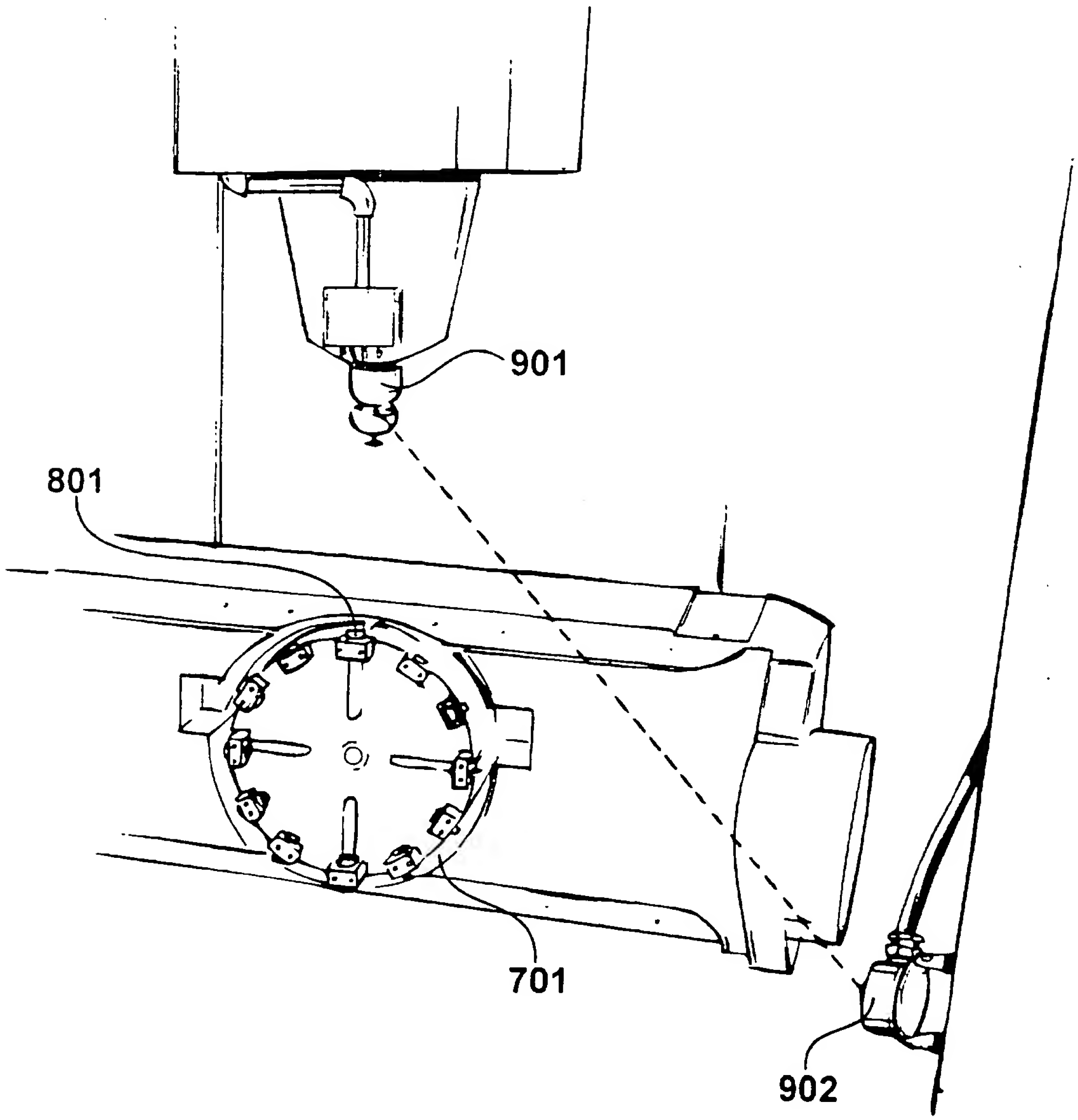


Figure 9

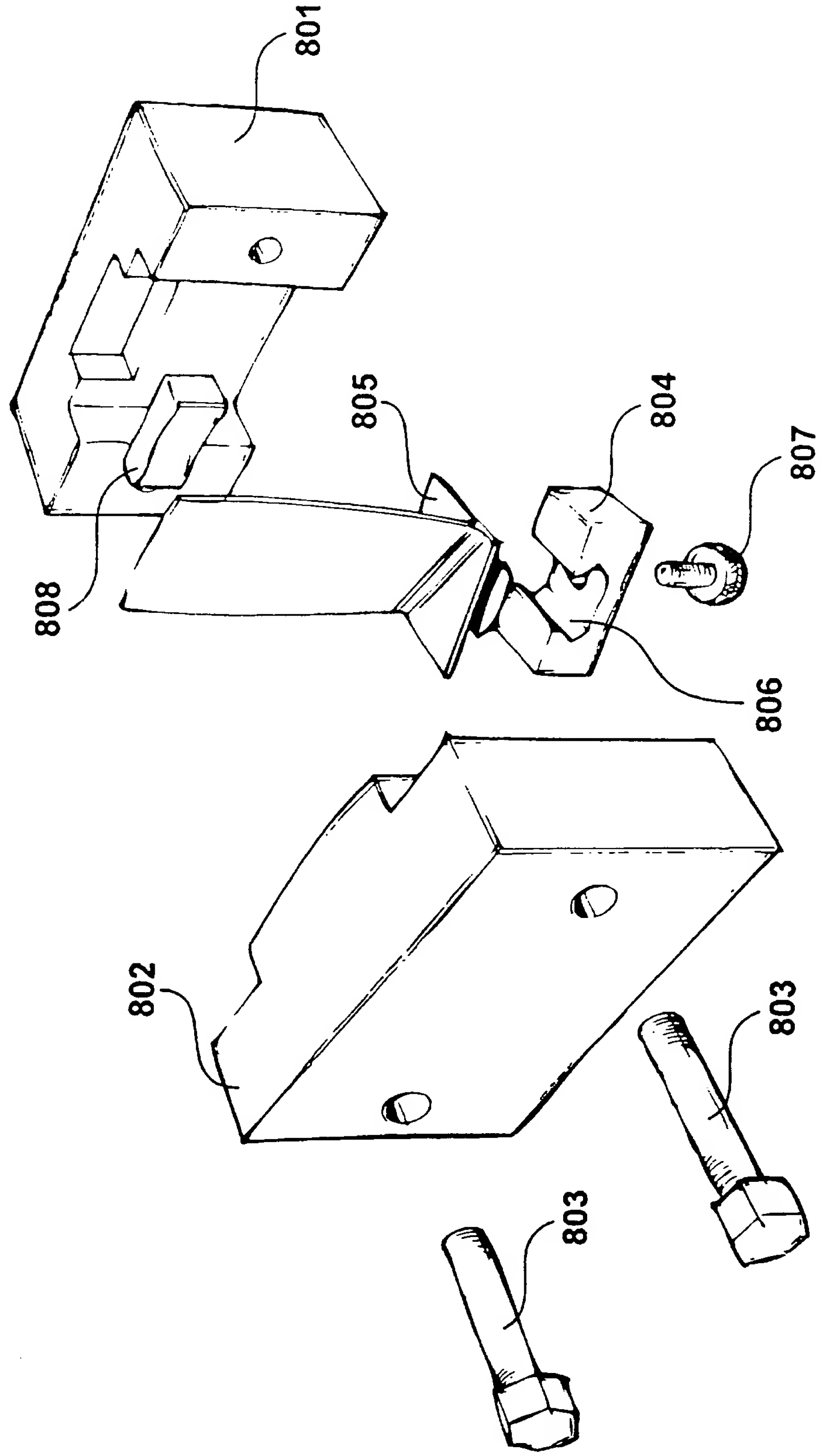


Figure 8

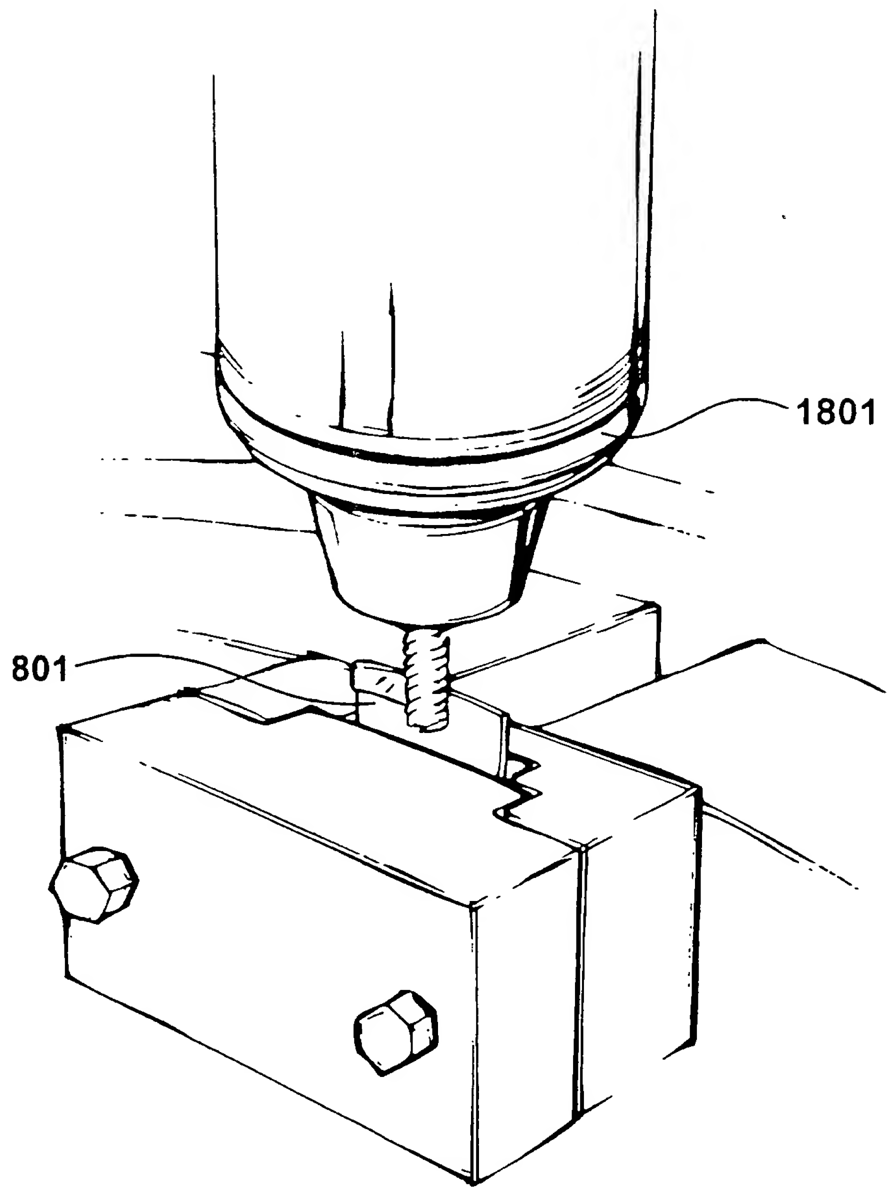


Figure 20

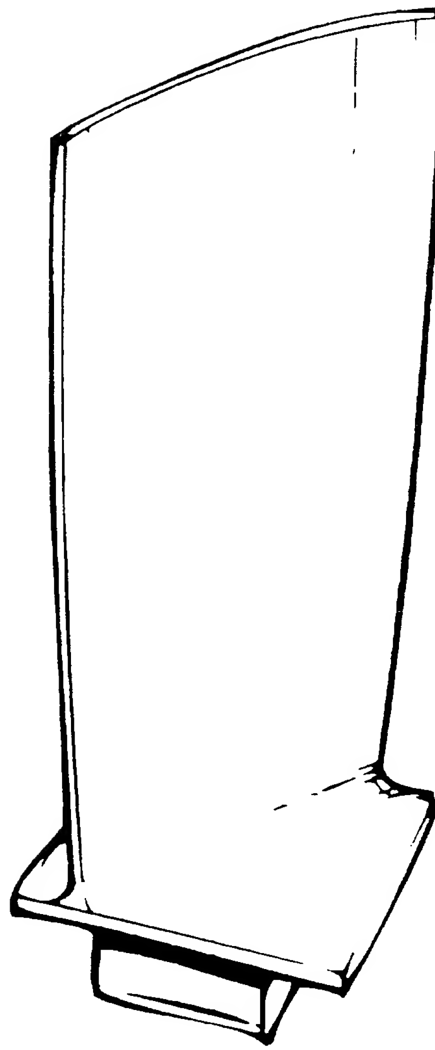


Figure 21

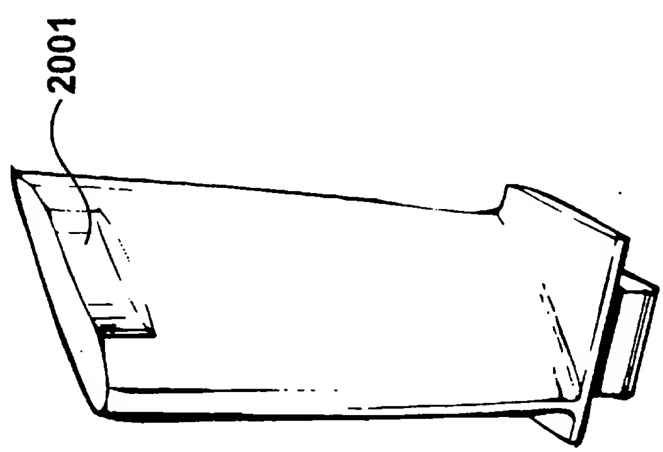


Figure 22A

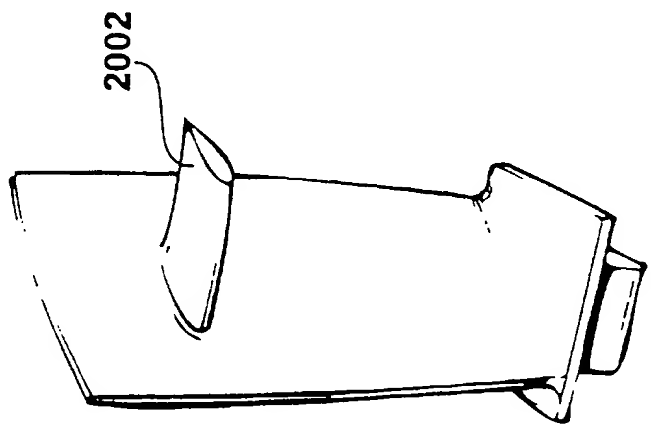


Figure 22B

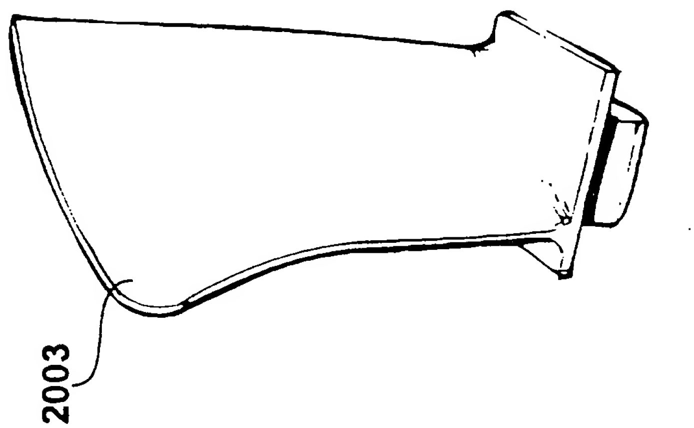


Figure 22C

2350809

Performing Mechanical Operations Upon Components

Field of the Invention

The present invention relates to performing mechanical operations upon components having initial surface shapes or configurations, in order to achieve desired surface shapes or configurations.

Background to the Invention

Many types of mechanical operations may be performed with very high levels of accuracy, resulting in the generation, modification or repair of components that are then virtually identically. It can be said that the components have been accurately operated upon in accordance with an engineering model and such an approach facilitates highly cost effective automation. However, not all components may be operated upon in this way, particularly if a degree of variation is present in terms of initial surface shapes and configurations etc. Thus, for example, a component may require a forging process followed by a machining process and the inherent nature of the forging process may result in components that have slight but not insignificant differences when compared one against the other. All of the differing components may be satisfactory, in terms of falling within acceptable tolerance constraints but these differences create problems in terms of attempting to apply the same machining program to each individual component in a manufacturing process.

In order to overcome these problems, it is known to perform machining operations manually, such that the engineering model becomes a guide that is adopted as far as possible, while accommodating differences present within an initial surface shapes and configurations. Consequently, such an

approach does not facilitate automation, thereby significantly adding to the overall manufacturing cost. Furthermore, by its very nature, the introduction of human subjectivity as part of the machining process places upper bounds on the tolerances within which it is possible to work.

An extreme example of this situation arises when a component is being repaired, such that part of its initial shape or configuration is now missing. Furthermore, variations between similar components, either through originally manufacture or through subsequent use, means that it is not possible to reconstitute the missing portion of the component merely with reference to originating design models. Thus, following known techniques, it is necessary to repair components of this type with significant manual intervention, in order to ensure that the new component satisfies the design requirements, while at the same time ensuring that the newly added portions are consistent with existing fabrications.

Summary of the Invention

According to an aspect of the present invention there is provided a method of performing mechanical operations upon components having initial surface shapes or configurations, in order to achieve a desired surface shape or configuration, comprising the steps of identifying an engineering model defining a preferred surface shape or configuration for a component; deriving a description of at least a part of said initial configuration; defining a component model by manipulating said engineering model with reference to said description; and performing mechanical operations upon said component in response to said component model.

In a preferred embodiment, the mechanical operations are performed by a numerically controlled machine tool and said operations may comprise

milling, grinding, cutting, drilling, buffing or polishing components.

Cutting and drilling operations may be performed using conventional blades and drill bits. However, alternatively, these operations could also be performed using lasers or high pressure water jets etc.

Preferably, the engineering model is identified from original design specifications, by analysing a finished component or by synthesising constructions within a computer aided design environment. Preferably, a description of at least a part of said initial configuration is derived by probing a surface profile to identify component locations. Preferably, probing locations are compensated for probe size by calculating a probed surface and applying an off-set from said probed surface to determine a new surface description.

According to a second aspect of the present invention, there is provided apparatus for performing mechanical operations upon components having initial surface shapes or configurations in order to achieve a desired surface shape or configuration, comprising identifying means for identifying an engineering model defining a preferred surface shape or configuration for a component; deriving means for deriving a description of at least a part of said initial configuration; defining means for defining a component model by manipulating said engineering model with reference to said description; and performing means configured to perform mechanical operations upon said component in response to said component model.

Brief Description of the Drawings

Figure 1 illustrates an aeroplane engine, with a cut-away showing a rotor assembly;

Figure 2 shows a damaged compressor blade removed from the rotor

assembly shown in *Figure 1*;

Figure 3 shows a blade held firmly within a vice and having a damaged tip removed by a milling operation;

Figure 4 shows the addition of material by means of a welding operation performed on the machined tip shown in *Figure 3*;

Figure 5 illustrates important procedural steps of the preferred embodiment;

Figure 6 illustrates a machine tooling environment for implementing the procedures identified in *Figure 5*;

Figure 7 illustrates a trunion for securing a work piece within the environment shown in *Figure 6*;

Figure 8 illustrates the mounting of a component within a mounting block;

Figure 9 illustrates the application of a plurality of mounting blocks of the type shown in *Figure 8* to a trunion of the type shown in *Figure 7*;

Figure 10 represents a wire mesh illustration of an engineering model for a component to be machined;

Figure 11 illustrates a two dimensional profile of the engineering model derived from the three dimensional model of *Figure 10*;

Figure 12 shows a probing process for deriving a description of an initial configuration;

Figure 13 details the process for performing the probing operations, *identified in Figure 5*;

Figure 14 illustrates recorded locations produced by a probing process;

Figure 15 illustrates the generation of a best-fit curve from the points illustrated in *Figure 14*;

Figure 16 illustrated the application of an off-set to compensate for probe diameter;

Figure 17 illustrates the overlaying of a model profile against a measured description;

Figure 18 illustrates a complete component model;

Figure 19 details procedures for the generation of a machine tool program, identified in *Figure 5*;

Figure 20 illustrates the operation of the machine tool in order to complete the component, identified in *Figure 5*;

Figure 21 illustrates the finished component produced by an execution of the preferred embodiment; and

Figure 22 illustrates alternative components produced using similar techniques.

Detailed Description of The Preferred Embodiments

The invention will now be described by way of example only with reference to the previously identified drawings.

An aeroplane engine **101** is illustrated in *Figure 1*, as an example of an environment where the present invention may be advantageously exploited. The engine **101** includes a rotor assembly **102** having a plurality of compressor blades **103**. During operation, compressor blades **103** are subjected to severe operating conditions in terms of operating temperatures and forces applied thereto. Compressor blades also become damaged and after a certain degree of damaged has taken place, a damaged blade must be either replaced or repaired. Although compressor blades become distorted through use, the turbine as a whole will have been balanced with these distorted blades in place, therefore the fitting of new blades may result

in turbine unbalance. Furthermore, a period of running-in will be required when new compressor blades are fitted. Thus, in addition to the obvious cost implications, it is advantageous to repair existing balanced blades if this is at all possible.

A damaged compressor blade **201** is illustrated in *Figure* 2, having been removed from a turbine for manual inspection. The blade has been removed from the rotor of a jet engine and has suffered damage due to the impact of foreign bodies drawn along with the air into the engine. In the example shown in *Figure* 2, the damage is predominately to a tip portion **202** and damage also often occurs to a leading edge portion **203**. Each blade **201** includes a mounting assembly **204** that tends to be of substantially constant shape and configuration. However, the blade itself has a complex three dimensional geometry that is often distorted from an optional engineering design; particularly due to the forging operations effected during its manufacture and to the harsh operating environment of the blades.

Blades may be refurbished by the addition of material under a welding process, whereafter a machining operation is performed so as to return the blade substantially to its original shape and configuration. However, this machining process must be performed in a way that is sympathetic to the distortions introduced into the blade and, for this reason, known approaches have often involved a significant level of manual intervention.

Referring to *Figure* 3, the blade **201** is held firmly within a vice **301** by its fixing portion **204**. The geometry of fixing portion **204** tends to be relatively identical between components and thereby effectively provides a datum from which surface configurations of the blade may be measured. It is the geometry of the blade extending from the fixing portion that undergoes significant degrees of distortion, both during manufacturing processes and

during use. The rough edge of tip **201** is removed by a milling machine 302 to present a milled blade tip **303**. Thereafter, as shown in *Figure 4*, additional material **401** is added to the new blade tip **303**, to the extent that the welded blade is now larger than a new blade of similarly type. However, due to original manufacturing imperfections and subsequently introduced distortions, it is not possible to machine the welded tip with reference to a fixed engineering model. Thus, the present invention embodies an approach which allows components of this type to be machined automatically in a way which is sympathetic to the individuality of each unique component, while at the same time making reference to an original engineering model so as to ensure that the resulting finished component is consistent with the original design requirements.

Important procedural features of the invention are identified in *Figure 5*. At step **501** an engineering model is identified for the component, representing an originally optimised design which, ideally, would be met for all of the individual components manufactured in accordance with that design. As described subsequently, this engineering model is represented in the form of a three dimensional surface, manipulatable within known computer aided design (CAD) and computer aided manufacture (CAM) packages.

At step **502**, a description of an initial configuration is derived, specifying the particular configuration for an actual component in its initial state. Thus, the initial description may refer to a component that is being repaired, as previously described with reference to *Figure 1* to *Figure 4*, or it may describe a new component at a partial stage of the manufacturing process. Thus, the derived description may represent aspects of a forging prior to further machining operations being performed. Thus, step **501**

identifies the originating engineering model and step **502** derives a description of the actual configuration of a particular device. Thereafter, at step **503**, the engineering model is manipulated with the component's initial description to produce a component model, specific to the particular component under consideration but sympathetic with the original engineering model.

From the component model generated at step **503**, a machine tool program, suitable for operating a computer numerically controlled (CNC) machine tool is generated, whereafter at step **505** the machine tool is operated in response to the generated machine tool program.

After the machine tool has been operated at step **505**, a question may be asked as to whether another component type is to be processed and, when answered in the affirmative, control may be returned to step **501** and the procedures repeated. Thus, the system is configured such that many individual components may be machined in response to a particular engineering model while, furthermore, many different types of engineering model may be followed, thereby enhancing the system's overall flexibility.

A machine tool environment for implementing the procedures identified in *Figure 5* is detailed in *Figure 6*. In accordance with conventional practice, the environment includes a machine tool station **601** and a machine tool control station **602**. Instructions, usually in the form of G-codes, may be generated locally at the control station **602** in order to operate the machine tool station **601**. Furthermore, a plurality of such codes may be collected into a command file, allowing the combination of the machine tool station **601** and the machine tool control station **602** to perform complex machining operations within their own local environment.

In addition to stations **601** and **602**, the environment shown in *Figure 6*

also includes a CAD/CAM system **603**, including a display device such as a visual display unit (VDU) **604** and input devices such as a keyboard **605** and a mouse **606**. Furthermore, the CAD/CAM system **603** communicates with the machine tool control station **602** via an appropriate communication channel, such as an RS232 serial interface or via an Ethemet network.

Within the machine tool station **601**, as detailed in *Figure 7* a workpiece is secured to a rotatable trunion **701**, configured to rotate in the direction of arrow **702** and to rotate in the direction of arrow **703**. The axes of rotation for the above intersect at an origin **704**, from which all positions within the facility are measured. In addition to these two rotational components, configured such that a workpiece is made to rotate, the machine tool itself may also undergo translation in three linear dimensions, represented by a vertical axis **705**, a horizontal axis **706** and a second horizontal axis **707**.

A workpiece, or a plurality of work pieces, are secured to trunion **701**, whereafter machining operations are performed on each of said workpieces in response to control instructions supplied to the machine tool station **601** from machine tool control station **602**.

In the present embodiment, twelve individual components are mounted to trunion **701** and the machine is programmed to derive a description for each of the twelve components, process each of these descriptions with the component model, generate a machine tool program specific for each of the twelve components and then operate the machine tool, in response to each specific component model, so as to perform individual mechanical operations for each component in response to their respective component models.

During all of the said operations within the machine tool environment,

the component itself must be securely held in place so that its position does not move with respect to its mounting, so as to ensure that it's surfaces maintain an accurate relationship with respect to the datum throughout the measuring and machining operations.

A mounting block for securing a single component to trunion 107 is detailed in Figure 8. The mounting block comprises a first mounting portion 801 secured to a second mounting portion 802 by means of bolts 803. The arrangement also includes a securing bracket 804 within which base 805 of the component is receivable therein by means of a closely fitting grooved channel 806, whereafter said component is firmly secured by means of a bolt 807. A nylon pad 808 is receivable within block 801, thereby ensuring that pressure is applied substantially towards the top of the component, so as to ensure that the component cannot move within the mounting block while probing and measuring operations are being performed.

A trunion **701** having twelve mounting blocks secured thereto, each having a component for machining extending therefrom, is illustrated in *Figure 9*. For each component, a description of its initial configuration is obtained using a probe **901**, sensitive to detecting a situation to the effect that contact has been made between the component and the probe. Thus, when such a situation arises, infrared emitters surrounding the probe generate an encoded infrared signal that is detected by infrared detector **902**.

For each component, probe **901** is instructed to perform a probing operation, which consists of traversing in predetermined orientations that are substantially perpendicular to edges of the component **801**. The probe then produces an indication to the effect that the component has actually been contacted. Thus, in this way, a set of location points are identified, from which an outline profile of the particular component under consideration is

determined.

Thus, with components **801** firmly held in place on trunion **701**, operations are performed to derive a description of an initial configuration for each of the components by probing, whereafter the descriptive data is manipulated in combination with engineering model data to produce a component model, followed by machine tool operations being performed in response to a generated machine tool program.

As described with reference to *Figure 5*, the first stage of this procedure consists of identifying an engineering model. A suitable engineering model may be derived in several ways. The original components may have been designed using CAD/CAM systems, thereby making an appropriate model readily available. Alternatively, if a model of this type is not available, it is possible to reconstitute the model by performing appropriate probing operations upon a typical example of a new finished component. Alternatively, when only partial components are available, it is possible to probe part of the component and then synthesise or reconstitute a model of the component using CAD design tools. In any event, an initial engineering model is processed to produce a processed engineering model, suitable for being adapted in response to specific component measurements, resulting in the production of a component model.

An initial engineering model of the type manipulated by CAD/CAM systems defines surface configurations by means of mathematical equations. In this way, it is possible to consider a surface in terms of a plurality of surface points, where points of this type may be generated at any required definition. These surface definitions of the initial engineering model are processed to produce surface locations is three dimensional space, from which it is possible to construct a wire frame representation taking the form of

specified surface positions connected by surface profile lines.

A set of specified surface positions connected by the same surface profile line are considered to be associated surface positions. In this way, an adaptation is performed by making calculations to determined the extent to which an individual surface position requires adaptation and then using this value to perform similar adaptations to associated surface positions. In this way, it is possible to apply appropriate adaptations to all surface positions defined within the processed engineering model.

In order to facilitate this procedure, the initial model is processed by applying an off-set to surface positions of a fixed amount so as to enlarge the enclosed volume defined by the mesh. In this way, a collection of points representing a derived description of a initial configuration may be placed entirely within the expanded model, whereafter the positions of the model are moved so as to occupy locations of the measured surface locations, to determined the degree of off-set required in order to effect this transformation. Transformations of this type are calculated along a particular profile in order to produce a set of off-set transformations. Then, with reference to each of these off-set positions, the remainder of the position defined within the model are similarly off-set by considering associated surface positions along an associating profile.

As used herein, points defined on a mathematical surface within the CAD system will be referred to as positions, whereas points on the actual surface of the workpiece will be referred to as locations. A description, usually in CAD terms, of the original engineering component will be referred to as an initial engineering model and such an engineering model may be produced in many ways, as previously described. In order to be used within the environment of the present embodiment, as described with reference to

Figure 5, the initial engineering model is processed in order to produce a processed engineering model, of the type suitably modified for manipulation in combination with the descriptive data of the actual component itself. Thus, for each particular application type, it is necessary to analyse the component and its further machining requirements in order to assess an appropriate portion of the existing component from which an initial configuration description may be derived and then to determine, in relation to this description, an appropriate modification to an initial engineering model in order to produce a processed engineering model.

In the present embodiment, a horizontal profile of an existing component may be analysed substantially in a single plane to produce an appropriate description. It is then necessary to extrapolate these measurements vertically, with reference to a processed engineering model, in order to reconstitute positions of the generated component model, which are then reflected in new component locations after the programmed machining process.

The processing of a processed engineering model in order to produce a component model involves determining the extent to which a portion of the engineering model must be modified in order to bring it into line with a similar portion of the derived description. Under these circumstances, a problem could arise in that a definition of the engineering model could be modified, thereby bringing it to the boundary of the surface locations, in a way that takes the model in the wrong direction. In order to avoid this, the processed engineering model is processed in such a way as to make it purposefully larger than the initial engineering model such that modifications, in order to find the position of component locations, always involves off-setting the processed engineering model inwards.

A processed engineering model for the application of the preferred embodiment is shown in *Figure 10*. In vertical direction **1001**, the dimensions of the model remain unchanged when considered with respect to the initial engineering model. However, the dimensions in directions **1002** and **1003** have been expanded by means of applying an arithmetic off-set. Consequently, the defined shape has the same height as the portion of the component being considered but it is significantly fatter.

Points **1004**, **1005**, **1006**, **1007**, **1008**, **1009**, **1010**, **1011**, **1012**, **1013**, **1014** and **1015** are connected by a substantially horizontal profile line **1016**. By being connected by this profile line, the positions **1004** to **1015** are considered to be associated.

Other profile lines are defined lying substantially parallel to profile line **1016**. In addition, points are connected by substantially vertical profile lines, effectively extending substantially in the dimension 1001. Thus, by means of vertical profile line **1017**, positions **1006**, **1018**, **1019** and **1020** are associated. Furthermore, these vertical associations are used in order to effect transformations of the overall model. Consequently, these associations are referred to as transformation associations.

Step **503** for manipulating the processed engineering model to produce a component model involves selecting profile **1016** and considering this in two dimensions with respect to an agreed datum, as illustrated in *Figure 11*. Thus, profile **1016** is shown in *Figure 11* as a cross-section through the model, such that a description of actual component locations may be located within said profile, thereby allowing comparisons to be made and off-sets calculated for each of the positions shown in *Figure 11*, whereafter similar off-sets may be applied to each further position, by means of a transformation association, such as the transformation association

defined by profile **1017**, shown in *Figure 10*.

The engineering model identified at step **501** and displayed in *Figure 10* may be used to generate a probing routine for probe **901** or alternatively a manual probing exercise may be performed against a representative sample of an actual product. The resulting probing activity is detailed in *Figure 12*. The probe itself includes a vertical extending probe rod **1201** with a disc **1202** of known diameter centrally located and extending horizontally therefrom. As the probe approaches component **801**, in a way such that disc **1202** contacts an initial and unmodified portion of the component, below the level of the weld seam. The probe approaches the component on each pass in a way such that the disc **1102** strikes the component at a substantially perpendicular orientation. If the probe fails to make contact with the component under any particular pass, a major fault must have occurred, resulting in the process being halted and this condition is brought to the attention of an operator. The probe passes are configured such that all accepted components, mounted in the correct way, will result in the disc **1102** striking the surface of the component.

In alternative applications, a probe having a more conventional ruby ball may be employed but in the present embodiment a disc is used in order to overcome the welded bead.

A file of data representing the probing path may be retained on system **603** and then downloaded to the machine tool control station **602** when deriving a description of the initial configuration as required by step **502.** Thus, the procedures of step **502**, as detailed in *Figure 12*, are effected by machine tool control processor **602**.

Referring to *Figure 13*, process **502** is initiated by the control station **602** asking whether probing data is available at step **1301**. If the data is not

available, a facility **1302** allows a specimen of the component to be probed so as to generate new probing data.

With the probing data is made available, a question is asked at step **1203** as to whether the machine has been loaded successfully. In accordance with conventional practice, machine tool station **601** includes a plurality of safety interlocks and further operation is only possible if all safety requirements, such as the closing of doors, have been satisfied.

If the question asked at step **1303** is answered in the negative, to the effect that the machine is not loaded or is not suitably configured for operation, the processor enters a wait state at step **1304** and asks the question again after a predetermined wait period. Ultimately, the question asked at step **1303** should be answered in the affirmative, resulting in a component being selected at step **1305**. At step **1306** the component is probed to determine a component description, taking the form of a plurality of three dimensional points, details of which are stored as a file representing the component description. Thereafter, at step **1307** a question is asked as to whether another component is to be probed which, if answered in the affirmative, results in control being directed to step **1205**.

Thus, it should be appreciated that all of the components attached to trunion **701** are probed, with a suitable indexing of the trunion taking place, before any of the components are machined. In this way, the processing is optimised by minimising the number of tool changes.

By necessity, due to the presence of the weld seam, the component is probed by disc **1202**, as shown in *Figure 12*. As the probe approaches the component, contact is made and the exact location at which this contact takes place is then recorded. This results in a plurality of locations being recorded, of the type illustrated in *Figure 14*. However, it should be

appreciated that these location points do not actually represent points on the component's surface but represent a displacement from the component's surface equal to the diameter of disc **1202**. Thus, locations **1401**, **1402** and **1403** etc represent locations displaced from the component's surface, due to the diameter of disc **1202**.

In order to determine the position of actual locations on the component's surface, the location points in *Figure 14* are analysed in order to produce a best-fit curve **1501**, as illustrated in *Figure 15*. Having produced curve **1501**, the originally measured locations **1401**, **1402** etc may be discarded, thereby leaving a mathematical description of curve **1501**. The determination of curve **1501**, as a best-fit curve, deals with the problem associated with the probe striking the component at non-optimal angles and as such represents an outline displaced from the contour of the component itself by a fixed value equal to the diameter of disc **1202**. Consequently, it is now possible to take account of this off-set, as shown in *Figure 16*. Thus, from the mathematical description of curve **1501**, perpendicular off-set vectors **1601** are determined, having a magnitude equal to the radius of disc **1202**. From these vectors, an off-set profile **1602** is determined and described in mathematical fashion. New curve **1602** therefore represents the outline of the component itself, which is then in turn used as the description of the initial configuration.

The processed engineering model illustrated in *Figure 11* is manipulated with the component description shown in *Figure 16* by overlaying the profiles with respect to a common datum, as shown in *Figure 17*. As previously described, the processed engineering model includes a plurality of associated positions, such as positions **1007** and **1008**, each associated to other positions within the three dimensional model by means

of transformation associations. From each specified position of the processed engineering model, the component profile **1602** is considered so as to identify the closest location on said profile to each of said specified positions. Thus, from position **1008** on the model profile, location **1708** on the component profile is identified. Location **1708** is then specified not in terms of its absolute location within the space being considered but in terms of a vector **1728** from position **1008**. Similar vectors **1724**, **1725**, **1726** to **1735** are determined for all positions on the model profile **1016**, each representing a direction and a minimum distance through which it is necessary for a position on the model profile to be translated to a location on the component profile. Thus, all of the positions defined on the model profile are now associated with a transformation vector and these vectors are then employed to perform related transformations, via the transformation associations.

In some models, it may be preferable to modify the vectors illustrated in *Figure 17* before these vectors are applied through the transformation associations. However, in the present embodiment, similar vectors are employed in order to manipulate the three-dimensional model.

Referring to *Figure 10* in addition to *Figure 17*, position **1006** has resulted in the calculated of vector **1726**, required in order to translate position **1006** to location **1706**. Having calculated a transformation for position **1006**, it is now possible to exploit this transformation in relation to the transformation associations. Referring to *Figure 10*, the transformation associations for position **1006** are positions **1018**, **1019** and **1020**. Thus, in addition to position **1006** being translated in accordance with vector **1726**, a similar translation, under the influence of vector **1726**, is performed with respect to positions **1018**, **1019** and **1020**. This procedure is then repeated

for all of the positions on profile **1016**, with respect to their vector transformation, thereby transforming all of the transformation associations. Thus, for example, position **1007** is translated to location **1707**. A similar transformation is then performed with respect to positions **1021**, **1022** and **1023**. In this way, the whole of the process engineering model is manipulated in response to the transformation vectors in order to produce a complete component model, as shown in *Figure 18*.

Thus, the component model shown in *Figure 18* has been derived from the processed engineering model and this model has been adapted in response to the derived description of the initial configuration. Vectors, as shown in *Figure 17*, have been determined for a particular profile and these vectors have been exploited in order to achieve an adaptive manipulation of the whole processed engineering model.

The generation of a machine tool program is performed predominately by the CAD/CAM system **603** and preferably this processing is effected while the probing tool is being replaced by a cutting tool. Alternatively, the machine tool program for a specific component may be generated after each description has been processed with the component model data, if found to bring about a more optimum solution. In any event, it should be appreciated that the CAD/CAM system **603** operates within a multi-tasking environment, such as Unix or Windows NT, such that intensive processing calculations may be effected when processing capacity becomes available.

Procedures **504** for the generation of a machine tool program are detailed in *Figure 19*. At step **1901** a component model is selected and at step **1902** a tool path is fabricated from the component model. The generation of a tool path is performed by the CAD/CAM system **603** and

may use commercially available CAD software, such as DUCT supplied by DELCAM, Birmingham, GB. The tool path takes account of tool radius and applies an off-set, thereby representing operations of the centre line for the cutter path. The paths are defined as absolute positions (XYZ) in combination with directional vectors (IJK) and the resulting data, also known as an NC part program, is represented in the form of a binary file.

At step **1903**, the tool path NC part program is processed to produce a cut file which, in addition to the tool path data, also includes data defining coolant requirements and cutting speeds etc. The cut file, having been generated by CAD system **603**, is transferred to the machine tool control station **602**, whereupon a post processing operation is performed at step **1904** so as to assemble the cut file into a tape file. The cut file has a substantially generic format allowing it to be supplied to many different configurations. However, post processing performed by the tool control station **602** produces a tape file that is specific to the particular machine tool station **601** being employed.

At step **1905**, the tape file is supplied to the CNC machine tool station **601** from the tool control station **602**. In this respect, the tape file is processed by the machine tool in a substantially similar way to the processing of a command file and the commands generated from the tape file are substantially similar to ASCII G-codes, as previously described.

In response to receiving commands from the tape file, the machine tool operates as identified by step **505** and as detailed in *Figure 20*. A milling operation is performed by the machine tool **2001** while component **801** is held firmly in location. Machine tool **2001** is operated along axes **705**, **706** and **707**, with additional cutting orientations being facilitated by rotations about axes **702** and **703**. After a first component has been

machined, the next tape file is selected, trunion **701** is indexed and the operation is repeated.

A fully machined component is illustrated in *Figure 21*, conforming to the original engineering model description but at the same time taking account of subtle variations and distortions of the original component, such that a component repaired in this way is, in many applications, preferable to selecting a new component. Furthermore, components may be manufactured in this way at substantially lower costs compared to manual machining techniques and when compared to the manufacture of new components.

More sophisticated configurations may be introduced into the engineering model, as shown in *Figures 22A*, *22B* and *22C*. A blade is shown in *Figure 22A* having a squealer **2201**; a blade shown in *Figure 22B* has a snubber **2202**; and a blade shown in *Figure 22C* has an extension portion **2203**.

Claims

1. A method of performing mechanical operations upon components having initial surface shapes or configurations, in order to achieve a desired surface shape or configuration, comprising the steps of

identifying an engineering model defining a preferred surface shape or configuration for a component;

deriving a description of at least a part of said initial configuration;

defining a component model by manipulating said engineering model with reference to said description; and

performing mechanical operations upon said component in response to said component model.

2. A method according to claim **1**, wherein said mechanical operations are performed by a numerically controlled machine tool.

3. A method according to claim **2**, wherein said mechanical operations comprise milling, grinding, cutting, drilling, buffing or polishing components.

4. A method according to claim **1**, wherein said engineering model is identified from original design specifications, by analysing a finished component or by synthesising constructions within a computer aided design environment.

5. A method according to claim **1**, wherein a description of at least a part of said initial configuration is derived by probing a surface profile to

identify component locations.

6. A method according to claim **5**, wherein probing locations are compensated for probe size by calculating a probed surface and applying an off-set from said probed surface to determine a new surface description.

7. A method according to claim **1**, wherein said component model is defined by calculating displacement vectors between model positions and component locations.

8. A method according to claim **7**, wherein said displacement vectors are applied to a plurality of associated model positions.

9. A method according to claim **7**, wherein an engineering model is processed by applying a known off-set so that said processed model fully surrounds sample locations of said component.

10. A method according to any of claims **1** to **9**, wherein a component has material added as part of the repair procedure, a profile of the original component is described and a machine tool program is calculated for completing the repair of said component by the removal of excess material.

11. Apparatus for performing mechanical operations upon components having initial surface shapes or configurations in order to achieve a desired surface shape or configuration, comprising

identifying means for identifying an engineering model defining a

preferred surface shape or configuration for a component;

deriving means for deriving a description of at least a part of said initial configuration;

defining means for defining a component model by manipulating said engineering model with reference to said description; and

performing means configured to perform mechanical operations upon said component in response to said component model.

12. Apparatus according to claim **11**, wherein said mechanical operations are performed by a numerically controlled machine tool.

13. Apparatus according to claim **12**, wherein said numerically controlled machine tool receives instructions and control data from a computer-aided design/computer-aided manufacture system.

14. Apparatus according to claim **12** or claim **13**, wherein said mechanical operations comprise milling, grinding, cutting, drilling, buffing or polishing components.

15. Apparatus according to any of claims **1** to **14**, wherein said components are blades for jet engines.

16. Apparatus according to any of claims **1** to **15**, wherein said components have been repaired by the application of additional material and said mechanical operations are performed in order to remove excess portions of said additional material.

17. Apparatus according to any of claims **1** to **16**, wherein said identifying means is configured to identify an engineering model by receiving original design specifications, analysing a finished component or by synthesising constructions within a computer-aided design environment.

18. Apparatus according to any of claims **11** to **17**, wherein said deriving means is configured to derive a description of at least a part of said initial configuration by probing a surface profile to identify component locations.

19. Apparatus according to claim **18**, including a mechanical probe configured to probe said surface profile, including means for detecting a contact location and means for transmitting data indicating that a contact has taken place.

20. Apparatus according to claim **18** or claim **19**, wherein said deriving means is configured to compensate probed locations for probe size by calculating a probed surface and by applying an off-set from said probed surface to determine a new surface description.

21. Apparatus according to any of claims **11** to **20**, wherein said defining means is configured to define said component model by calculating displacement vectors between model positions and component locations.

22. Apparatus according to claim **21**, wherein said defining means is configured to apply said displacement vectors to a plurality of associated model positions.

23. Apparatus according to claim **21** or claim **22**, wherein said defining means is configured to process said engineering model by applying a known off-set to said model so that a processed engineering model fully surrounds sample locations of the component.

24. Apparatus according to any of claims **1** to **23**, including welding means for adding material to a component to effect a repair to said component, wherein said deriving means derives a description of a two dimensional profile of the original component, whereafter said performing means is configured to complete the repair of said component by effecting the removal of excess material over three dimensional surfaces of said component.

25. A computer-readable medium having computer-readable instructions executable by a computer such that, when executing said instructions, a computer will perform the steps of:

identifying an engineering model defining preferred surface shape or configuration for a component;

deriving a description of at least a part of said initial configuration;

defining a component model by manipulating said engineering model with reference to said description; and

performing mechanical operations upon said component in response to said component model.

26. A computer-readable medium having computer-readable instructions according to claim **25**, such that when executing said instructions

a computer will also perform the step of identifying said engineering model from original design specifications, by receiving locations as the result of probing a finished component or by assisting in the synthesis of a construction within a computer-aided design environment.

27. A computer-readable medium having computer-readable instructions executable by a computer according to claim **25** or claim **26**, such that when executing said instructions a computer will also perform the step of identifying component locations in response to a probing operation being performed along a surface profile of the component.

28. A computer-readable medium having computer-readable instructions according to any of claims **25** to **27**, such that when executing said instructions a computer will also perform the step of compensating probing locations for probe size by calculating a probed surface and applying an off-set from said probed surface to determine a new surface description.

29. A computer-readable medium having computer-readable instructions according to any of claims **25** to **28**, such that when executing said instructions a computer will also perform the step of calculating displacement vectors between model positions and component locations in order to define said component model.

30. A computer-readable medium having computer-readable instructions according to claim **29**, such that when executing said instructions a computer will also perform the step of applying displacement vectors to a plurality of associated model positions.

31. A computer-readable medium having computer-readable instructions according to claim **29**, such that when executing said instructions a computer will also perform the step of applying a known off-set to said engineering model so that a processed engineering model fully surrounds sample locations of said component.

32. A computer system programmed to control apparatus for performing mechanical operations upon components, having loaded executable instructions according to any of claims **25** to **31**.

33. A method of performing mechanical operations substantially as herein described with reference to the accompanying Figures.

34. Apparatus for performing mechanical operations upon components substantially as herein described with reference to the accompanying drawings.

The Patent Office

29

Application No: GB 9913360.5
Claims searched: 1-34

Examiner: Dave Butters
Date of search: 27 October 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): B3B, G3N

Int Cl (Ed.6): G05B

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2240406 A (HONDA)	
A	GB 2234089 A (GENERAL ELECTRIC)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.